The Experimental Study on Behaviour of Blended Cement Concrete with 80% Replaced with Nano-Metakaolin and Steel Slag at Elevated Temperature

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Abstract — The effect of high temperature up to 800˚C on concrete with 80% replacement of fine aggregate using nano-metakaolin, 80% replacement of fine aggregate using steel slag and their hybrid mix is compared to conventional concrete in this research work. Ordinary Portland cement containing fly ash is used as blended cement to prepare the concrete mix. M 30 grade concrete with water cement of 0.45 is used for the study. The project work involves casting of cubes (150mm x 150mm x 150mm), cylinders (150mm diameter and 300mm height) and prism (100mm x 100mm x 500mm). The concrete specimens are cured under water for 28 days and expose to 400 ˚C, 600 ˚C, and 800˚C for 1 hour. The compressive strength, spilt tensile strength and flexure strength are measured for these specimens and compared with the strength of conventional concrete. The strength of each mix is found to increase compared to conventional concrete and a greater increase in strength is observed in mix with partial replacement with nano-metakaolin. The strength is found to increase up to 600 ˚C and showed to decrease at 800 ˚C.

Keywords: nano-metakaolin, blended cement, steel slag, high temperature.

I. Introduction

Concrete is well known for its capacity to endure high temperature and fires owing to its low thermal conductivity and high specific heat. It does not mean that fire or high temperature do not affect concrete at all. High temperature may result in color change along with significantly affecting the compressive strength, modulus of elasticity, concrete density and its appearance. Therefore, many researchers have recently become increasingly interesting in the possibility of developing concrete that has better fire resistance so introducing the blended cement and Metakaolin and steel slag in concrete for investigation.

Blended cement are manufactured by adding pozzolanic or cementations materials like fly ash or ground granulated blast furnace slag or condensed silica fumes to Portland cement clinkers and gypsum. Alternatively these pozzolanic and cementations materials can be introduced in Portland cement concrete during casting of concrete.

Metakaolin is a Dehydroxylated form of the clay mineral kaolinite Stone that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. Steel slag is a by-product of steel making, and is produced during the separation of the molten steel from impurities in blast furnace. The slag occurs as a molten liquid and in a complex solution of silicates and oxides that solidifies upon cooling. Metakaolin is a Dehydroxylated form of the clay minerals kaolinite.

The particle size of Metakaolin is smaller than cement particles, but not as fine as silica fume, but nano-metakaolin is smaller than silica fumes. Steel slag, a by-product of steel making. It is produced during the separation of the molten steel from impurities in steel making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling.

Various test have been conducted to find the effect of nano-metakaolin on the consistency and setting time of cement. Test were also conducted to find the influence of nano-metakaolin on the properties of different grades of concrete. The variation of consistency of cement paste with addition of nano-metakaolin, is showing a gradual increase i.e., the percentage of water required for preparing a cement paste of standard consistency is increasing with the increasing in the amount of Nano-metakaolin. By adding the nano-metakaolin in to the concrete, the variation in the initial and final setting time of cement. The initial setting time of normal cement paste is 75 min. The initial setting time was found to increase as the replacement of nano-metakaolin up to 6% and above that it gets decreased. Compressive strength of reference specimen and the specimen containing percentage of nano-metakaolin is found to be increasing in compressive strength. Only up to a certain percentage the strength is getting increased beyond that the strength is found to decrease. In steel slag the maximum compressive strength values occurs at 25% slag ratio and declines beyond the 25% replacement ratio.

The slight improvement in strength may be due to shape, size and surface texture of steel slag. In almost all replacement ratios the flexural strength increased by the increase in slag ratio. Compressive strength, flexural strength and split tensile strength steel slag concrete were similar to conventional concrete. The strength may be affected with time and so long term effects on hardened properties of concrete required for further investigation.

Fig. 1. Heating specimen in High temperature furnace

II. Review of Literature

Till 300°C the concrete with pozzolanic material show better strength than the pure OPC concrete. Compared to conventional concrete limestone concrete shows larger decreasing in modulus of elasticity. Reaction of pozzolana with free lime gives better performance on blended cement. By using Nano Metakaolin in concrete will increase the fire resistance of the concrete. Blended cement improves the workability and water cement ratio. Thermal treatment of blended mortar at 250°C containing 15% Nano Metakaolin indicate the brittle property.

III. Need for the Research

To protect the depletion of natural resources, pozzolanic material is replaced in concrete. This research is done to increase the strength of blended cement with nano-metakaolin and steel slag. This research is done to construct building with high fire resistant properties.

IV. Experimental Investigation

In this study 2 mix are taken (M1 and M2) and this includes 21 samples of cubes (150X150X150) mm for compressive strength test and 18 samples of cylinders (150 diameter X 300 height) mm for split tensile strength test. All the samples have been prepared for conventional concrete and conventional concrete at elevated temperature (200˚C ,400˚C and 600˚C This sample were categorized by age of the concrete at the day of testing, for each mix 3 cubes and 3 cylinders were tested as trial. The specimens were tested at 7 days and 21 days of curing.

Table I. Designation of Mixes

Mix	Designation of Concrete
conventional concrete	M1
conventional concrete at elevated temperature at 200°c	M2
conventional concrete at elevated temperature at 400°c	M3
conventional concrete at elevated temperature at 600°c	M4

Various designation of mixes of conventional concrete at different elevated temperature is shown in Table-1.

Table II. Comparison of Compressive Strength

S. No	Type of Mix	Compressive Strength	
		7 Days (N/Mm^2)	28 Days (N/Mm^2)
1	M1	22	28
2	M2	22.6	28.6
3	M3	23.5	29.7
4	M4	cracked	Cracked

Table III. Comparison of Split Tensile Strength

S.no	Type of Mix	Split Tensile Strength	
		7 Days (N/Mm^2)	28 Days (N/Mm^2)
1	M1	2.46	3.9
2	M2	2.68	4.17
3	M3	2.97	4.45
4	M4	Cracked	Cracked

Table IV. Comparison of Flexural Strength

S.no	Type of Mix	Flexural Strength	
		7 Days (N/mm^2)	28 Days (N/mm^2)
1	M1	2.56	3.24
2	M2	3.02	3.9
3	M3	3.75	4.24
4	M4	cracked	Cracked

The compressive strength, Flexural strength and split tensile strength of conventional concrete members at three elevated temperature has been tested with 7 days and 28 days of curing are show in Table-2, Table-3 and Table-4.

Fig. 2. Compressive Strength Test of Cube Specimen

TABLE V. Chemical Properties of Steel Slag

Element	Weight%
Silica (SiO_2)	9.06
Iron(Fe_2O_3)	28.13
Iron(FeO)	24.33
Titanium (TiO_2)	35.42
Alumina(Al_2O_3)	01.213
Magnesium MgO	00.61
Calcium Ca	00.21
H_2O	00.18
Loss of Ignition	00.59

TABLE VI. Chemical Properties of Metakaolin.

Metakaolin Chemical Composition	Weight%
SiO_2+Al_2O_3+Fe_2O_3	>97.0
Sulphur Trioxide (SO_3)	<0.50
Alkalis (as Na_2O,K_2O)	<0.50
Loss on ignition	<1.00
Moisture Content	<1.00

TABLE VII. Physical Properties of Metakaolin

Metakaolin physical properties	
Specific Gravity	2.50 g/cm3
Colour	White
Physical form	Powder
+325 Mesh (45 μm) Residue	<1.0%
Average Particle Size	<2.5 μm

Physical and chemical Properties of Metakaolin and steel slag is shown in Table-5, Table-6 and Table-7.

C.C – Conventional Concrete
NM – Nano Metakaolin
SS – Steel Slag

TABLE VIII. 7th Day Compressive Strength at 200˚C

S.No	Type of Mix	C.C (N/mm^2)	NM (N/mm^2)	SS (N/mm^2)	Hybrid (N/mm^2)
1	M1	22	-	-	-
2	M2	-	29	24.8	27

TABLE IX. 7th Day Split Tensile Strength at 200˚C

S.No	Type of Mix	C.C (N/mm^2)	NM (N/mm^2)	SS (N/mm^2)	Hybrid (N/mm^2)
1	**M1**	2.46	-	-	-
2	**M2**	-	3.4	2.9	3.15

TABLE X. 7th Day Flexural Strength at 200˚C

S.No	Type of Mix	C.C (N/mm^2)	NM (N/mm^2)	SS (N/mm^2)	Hybrid (N/mm^2)
1	**M1**	4.9	-	-	-
2	**M2**	-	5.30	5.01	5.15

The seventh day testing of compression, split tensile and flexural strength at 200˚C for conventional concrete, nano-Metakaolin, steel slag and hybrid are shown in Table-8, Table-9 and Table-10.

CONCLUSION

In this study, the concrete with nano-metakaolin and steel slag is subjected to high temperature, which gives better result compare to conventional concrete.

Conventional concrete doesn't get affected up to 400˚C but beyond 600˚C it got cracked.

It was found that mechanical properties of conventional concrete got increased with the addition of nano-metakaolin and steel slag.

A greater increase was observed for compressive strength compared to other properties with the addition of these admixtures.

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